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ROME AIR DEVELOPMENT CENTER CRYO TEST FACILITY

CBI Na-Con

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ROME AIR DEVELOPMENT CENTER CRYO TEST FACILITY

Warren Carpenter

Contractor: CBI Na-Con
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INTRODUCTION

The Cryotest Facility Project for the Rome Air Development Center has been very successfully completed. All performance specifications have been met or exceeded. This project was also accomplished with very few cost changes from the original fixed price contract.

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FACILITY OVERVIEW

The Cryotest facility was specified and designed to determine the surface figure of 2m diameter optical elements under simulated space conditions. The space-simulation facility provides vacuum levels down to the 10^{-8} torr range and temperatures ranging from ambient temperature down to 100°K . The facility features a stainless steel 11'-6" diameter x 23' high vacuum chamber which includes a 7' high removable cylindrical section; a stainless steel thermal shroud; vacuum system; gaseous nitrogen (GN_2) thermal system; vibration isolation system; movable optic presentation stage; optic receiving, storage and cleaning area; office, laboratory and equipment rooms; and all ancillary systems.

The vacuum chamber is a vessel specifically designed for high-vacuum service utilizing a polished 304 stainless steel shell with carbon steel external stiffening. The chamber is also designed to have a resonant frequency of 30 HZ. The frequency specification is an overall frequency requirement and includes all chamber components from the optical benches to the presentation stage. The chamber is provided with numerous optical ports and feedthru ports. The chamber is designed to have a leak rate less than 2×10^{-7} std. cc/sec of helium.

The thermal shroud was provided by Dean Products and is an embossed stainless steel "Panel Coil" type shroud. The shroud is electropolished on the outside and painted with low outgassing rate, high-emissivity, 3M ECP-2200 paint. The shroud is divided into six thermal zones. Each zone is provided with a throttling valve to balance the flow through each zone.

The thermal system is a closed loop GN_2 system utilizing a cryogenic compatible blower, an electric, calrod type heater and a liquid nitrogen cooled shell and tube heat exchanger to cool the gas flow. The thermal system is capable of maintaining the shroud at any temperature between ambient and 100°K .

The blower is manufactured of stainless steel and is designed to operate throughout the entire temperature range of the thermal system. The blower is provided with an encapsulated motor such that the motor is contained within the pressure housing of the blower. This eliminated the single most likely failure point of a standard cryogenic blower which is the mechanical seal. The front motor bearing was provided with a special low temperature lubricant and heaters for use at 100°K .

The GN_2 chiller is an ASME Code stamped shell and tube heat exchanger. The GN_2 from the thermal system flows through the U-tube shaped tubes of the exchanger. Liquid nitrogen flows into the shell side of the heat exchanger and is used as the coolant for the GN_2 . After vaporization of the LN_2 , the vapor flows out of the top of the heat exchanger and is vented outside of the building. The shell side of the heat exchanger is provided with

a mesh pad type of phase separator and a high liquid level switch to prevent liquid carryover out of the vapor vent.

The GN₂ heater is a 15KW calrod type electric heater. The heater is supplied with an SCR type controller to modulate the heat output over the entire range from 0 to 15KW.

The vacuum systems consist of two 20" cryopumps and a roughing system. The cryopumps are manufactured by Leybold Heraeus. Each cryopump has a gross pumping speed of 10,000 L/S.

The roughing system included a Leybold Heraeus WAU 1000 roots-type blower, a S400F rotary vane roughing pump, and a Polycold trap. The roughing system is designed to evacuate the chamber to 2×10^{-2} torr in two hours.

A vibration isolation system is provided to reduce chamber vibration. The vibration isolation system included four Barry vibration isolators and flexible piping sections in all piping which attaches to the chamber.

An optic presentation stage is provided and functions as a cart to move the optic into and out of the chamber, a coarse height adjustment system to ensure that the optic is near its focal length from the interferometer and a three point fine adjustment system for final focusing of the optic. The coarse adjustment system operates over a 0 to 36" range with 1" maximum increments. The fine adjustment system operates over a $\pm 1/2$ " range with maximum increments of .001".

A control and data acquisition system was provided to control the entire facility and to store and print test data. The test data includes time, date, chamber pressure, shroud temperatures and test object temperatures. A graphics and data manipulation program was also provided for reports, data trending and other data manipulations.

An addition to Building 106 was provided to house the chamber, mechanical equipment, additional laboratory space, a Hartman test area, optic receiving area, optic storage and cleaning areas and office space. Major portions of the building addition were provided with a clean room filtering system and temperature and humidity control.

FACILITY CONSTRUCTION

The construction of the building was accomplished with only minor schedule delays and only three significant technical problems. The three problems included the discovery of a buried asbestos-insulated pipe, the discovery that the base steam system is shut down during the summer, and the lack of space for HVAC systems and ducting.

The discovery of the asbestos insulated pipe resulted in a shut down of the job while the asbestos was removed and disposed of.

The discovery that the base steam system was shutdown during the summer months required the addition of a small boiler to the HVAC systems to supply reheat during dehumidification operations and moisture during humidification operations.

The third significant problem was that too little space was allotted within the building for HVAC unit #1 and for HVAC ducting. This resulted in enlargement of the HVAC room and rerouting of the duct work.

The installation of the vacuum chamber and all associated equipment was accomplished with only one major problem. This problem was the significant delay of subcontractors to deliver components to the job site. By far the worst delivery problem was very late delivery of the vacuum chamber to the jobsite. This delay, caused by major errors of the subcontractor, resulted in approximately a 7 month delay in contract completion. In addition, the late delivery of the thermal shroud and the GN₂ blower caused minor problems with critical path work at the jobsite and at the thermal skid vendor's facility.

CBI also experienced a minor problem with the installation of the thermal insulation. Much of this insulation required rework because of the faulty installation.

FACILITY COMMISSIONING

The commissioning of the facility included checkout and start-up of all systems within the building. Checkout of the equipment included calibration of all instruments, electrical wiring checks, review of the control programs for the programmable logic controller (PLC) and for the data acquisition system (DAS), piping reviews, etc. Start-up involved the operation of all electronic and mechanical equipment.

The liquid and gaseous nitrogen system was commissioned first to provide GN₂ for instrumentation, valve operators and all other GN₂ users. This system operated as designed with the exception of the LN₂ vaporizer. The vaporizer was equipped with a PID (proportional, integral and derivative) type temperature controller which operated a SCR (silicon controller rectifier) to modulate the heat output of the electric vaporizer.

Due to the widely varying flow rate through the vaporizer, the temperature controller was incapable of reacting fast enough at high flow rates to prevent shutdown due to low GN₂ outlet temperature while preventing wild temperature swings at low flow rates. Basically a PID type controller can be tuned to function correctly at one constant flow rate or moderately different flow rates, but, can not be tuned to maintain a specified temperature with greatly differing flow rates.

It was therefore decided to replace the PID type temperature controller with a temperature switch set at 100°F. The temperature switch then activated the SCR to provide almost full power to the heater whenever the vaporizer temperature was below 100°F. This change worked well and no other major problems were encountered with the LN₂ and GN₂ system.

The vacuum systems functioned very well with little or no checkout or start-up problems. However during performance testing, both cryopumps did exhibit evidence of helium contamination. The two cryopumps required replacement of the displacers and purging of the helium system. The cryopumps were then operated extensively with no more evidence of contamination.

The thermal system was by far the most difficult system to checkout and start-up. This system is technically more complex, has more instrumentation and takes longer to start-up than any other system in the facility. A number of problems were encountered that needed correction. These problems included inaccurate thermocouples, blower motor overheating and condensing gaseous nitrogen in the GN₂ chiller.

The inaccurate thermocouples resulted in control problems and performance problems with the thermal system. The shroud thermocouple accuracies varied over a 10°F range when checked with saturated liquid nitrogen at -320°F. It was therefore decided to replace all shroud thermocouples with CBI fabricated thermocouples which reduced inaccuracies to approximately 4°F. The majority of other thermocouples within the thermal system also proved to be inaccurate. Two of the thermal system thermocouples (TE-0711-1 and TE-0711-2) in the thermal shroud inlet and outlet manifolds were used to control the shroud temperature. These thermocouples as well as supposedly more accurate replacement thermocouples proved to be too inaccurate for the control system. CBI therefore used the average of all of the shroud thermocouples for the shroud temperature control.

Another thermocouple which proved too inaccurate for its intended application was TE-0717. This thermocouple is used to shut the LN₂ valve to the GN₂ chiller if the GN₂ outlet flow from the chiller was below -294°F to prevent condensation of the GN₂ within the thermal system. This thermocouple and a replacement thermocouple were much too inaccurate for this service and were replaced with a CBI fabricated thermocouple.

The GN₂ blower motor was encapsulated within the blower pressure vessel to eliminate the need for a mechanical seal. However, the motor did not receive sufficient cooling when the thermal system was operating near ambient temperature. The blower vendor wrapped the outside of the motor housing with rectangular cooling water tubing and used heat transfer mastic to provide good thermal contact between the motor housing and the cooling tubing.

This proved to be a very effective solution to the problem. One gpm of cooling water resulted in a steady state motor temperature of 105°F as opposed to the uncooled motor temperature which was in excess of 260°F.

The other major problem associated with the thermal system was that this thermal system was designed to operate at the extreme low end (100°K) of the temperature range where GN₂ thermal systems are suitable for shroud temperature control. 100°K is at the low end of the GN₂ thermal system operating range because a few degrees below 100°K, GN₂ will start to condense within the thermal system. CBI's thermal system was cooled to 100°K a number of times within 4 hours while operating in manual control. However, it was impossible to use automatic control to achieve a four hour cooldown without condensing GN₂ within the thermal system when the shroud approached 100°K.

It was therefore determined that the four hour cooldown would be extended to approximately 10 hours to allow closer control of the thermal system temperature during cooldown. The change in cooldown time did not violate contract specifications and had no effect on the intended use of the facility. This change resulted in a well controlled thermal system that would smoothly ramp up or down in temperature and hold any temperature between ambient and 100°K as specified.

Another minor problem occurred when a similar GN₂ blower on another CBI project had a bearing failure. A subsequent review of the bearing design determined that the vendor's bearing design was in error. The RADC blower bearing was therefore replaced early in the facility commissioning with no difficulties or schedule delays.

The presentation stage including the coarse adjustment drive and the fine adjustment drive systems were commissioned with only one major difficulty. This problem resulted from poor quality control or poor shipping practices of the fine adjustment system stepping motor controller. Three of these controllers were provided to operate the three fine adjustment drive stepping motors. CBI had to repeatedly return faulty controllers until three controllers were obtained that would function properly. CBI believes that the faulty units were improperly repaired at the vendors facility or were damaged in shipment due to poor packaging. The faulty units would not operate immediately after installation and by switching the faulty controller with controllers that functioned properly CBI did isolate the problem area as the controller.

After three functional controllers were obtained and after minor adjustments to the structural components of the fine adjustment system and the presentation stage coarse adjustment system, the presentation stage system functioned properly.

The chamber bottom head lift and latch system were commissioned with no significant problems other than adjustment of the restrictor valves on the outlet of each side of each pneumatic cylinder. The adjustments, while not unexpected, were very time consuming in order to make the bottom head lift and lower in a level position and at the proper speed.

It appears that, due to the nature of pneumatic cylinder systems, if the bottom head center of gravity is significantly changed or if a full weight optic is installed in the chamber, the lift cylinder restrictor valves may have to be adjusted in order to maintain levelness or speed of travel.

The vibration isolation system was commissioned with no problems other than a tubing routing error during installation. The vibration system performed as expected. This system was commissioned without the 7' spool piece installed. If the spool piece is ever installed, it will be necessary to readjust the operating pressure from the current 55 PSIG setting.

The control systems including the PLC and DAS were commissioned with various logic changes. The logic changes for the DAS were a result of thermal control changes caused by the inaccurate thermocouples and the slower cooldown. The PLC changes were made to improve interlock safety and to make the automatic pumpdown logic work as specified.

PERFORMANCE TESTING

The performance testing of the facility went as smoothly as can be expected. All performance specifications were either met or exceeded. The only abnormal occurrence during performance testing was the previously mentioned contamination of a cryopump helium systems during the thermal system performance test.

The vacuum chamber was leak tested and found to have very few leaks. The leakage that exceeded the total leakage specification, 2×10^{-7} STD cc/sec of helium, was repaired and retested to specifications.

The vacuum performance testing was accomplished with absolutely no problems. The specified performance requirement was a pumpdown from atmospheric pressure to 8×10^{-6} torr in 5 hours. The performance test data proved the pumpdown to 8×10^{-6} torr in approximately 3 1/2 hours, significantly exceeding the specification. The chamber pumped down to 5.9×10^{-6} torr in 5 hours, and during commissioning the chamber has pumped down below 1×10^{-7} torr with the shrouds cold. This pumpdown data is based on an unconditioned chamber. Vacuum conditioning of the chamber will result in faster pumpdowns and lower ultimate pressures than that achieved during performance testing.

The thermal shroud performance test involved a cooldown of the shroud to a final temperature of 100°K. During the test, three

hold conditions were initiated. These holds demonstrated the controller's ability to maintain the test specimen temperature within operator specified limits. The first hold occurred when the difference between the average shroud and average test specimen temperatures exceeded an operator specified limit. The second hold occurred when the maximum temperature difference across the test specimen exceeded an operator specified limit. The third hold occurred when the average shroud temperature reached 150°K. Each hold lasted for a duration of one hour.

During the one hour hold at 100°K, the vacuum system and thermal system were shutdown and the fine adjustment system and shroud shutters were operated to simulate an interferometric test at 100°K.

The temperature difference across a thermally slow reacting optic was simulated by installing three thermocouples on the presentation stage.

The shroud was then returned to ambient temperature and held for approximately three hours to determine the maximum steady state temperature of the blower motor. As stated previously the motor reached a steady state temperature of only 105°F.

The thermal system performance test data proved all of the above requirements were accomplished.

The presentation stage was tested for load-carrying capacity, coarse adjustment operation and fine adjustment. The load test was performed to prove the specified loading of 1200 LB.

The coarse adjustment system was tested to prove an overall height adjustment range of 36" with the maximum increments of 1". These tests were performed with the 1200 LB load.

The fine adjustment system was tested with the presentation stage mounted in the chamber. The specified requirement was overall travel on each of the three support points of $\pm 1/2$ " with maximum increments of .001 inch.

The presentation stage system passed all performance requirements and significantly exceeded the specifications for maximum increments of movement on the coarse and fine adjustment systems. The minimum increment of coarse adjustment is 1/16" to 1/8" as opposed to the 1" maximum specified. The minimum increment of fine adjustment is less than .0001 inches as opposed to the specified .001 inch requirement.

The chamber repressurization performance test required repressurization times ranging from 30 minutes to 4 hours. Performance test results showed repressurization rates ranging from 25 minutes to 6 hours.

The facility control system, DAS system, LN₂ system and GN₂ system were tested by their ability to support all other performance tests. The PLC system was tested by its ability to operate all systems and its ability to run the automatic pumpdown logic. The interlock logic was also reviewed by RADC and consultants from SAIC and Ball Aerospace.

The data acquisition system was tested by using it to record all performance test data for the vacuum, thermal and repressurization systems performance tests. The DAS was also tested by its ability to perform its designed control tasks as part of the thermal system control equipment.

The LN₂ and GN₂ systems were tested by proving their ability to supply suitable flow rates of LN₂ and GN₂ for the performance tests of all other systems.

All of these auxiliary systems performed as specified or as required by other systems.

CONTRACT CHANGES

There were no major specification changes during the course of this project. There were, however, two minor changes to the specifications.

The first specification change was that each shroud zone was required to be provided with a flow meter. CBI suggested that a more effective flow control system for shroud valving, since the flowrate would be balanced during commissioning and should never change, would be to supply remote valve control from the control panel with digital valve position displayed at the panel and positioners on the valve. This was discussed with RADC during the design review meetings and approved by RADC.

The other minor change to the specification was a change in the minimum data recording rate for the DAS of 1 second. Due to the slowness of all processes in the facility, data recording rates less than 1 minute were not necessary. However, CBI agreed to provide recording rates of 10 seconds. This was discussed with RADC and approved by RADC.

NONCONTRACTUAL PROJECT CHANGES

These changes involved voluntary additions to the facility or approved deletions to the facility from the time of the CDR until contract completion. These changes do not affect contract requirements. Additions were added to improve performance and deletions had no affect on performance.

The additions included a cooling water system for the GN₂ blower, high motor temperature, high current and high bearing temperature blower shutdowns, thermal system GN₂ purge line, GN₂ blower suction strainer with differential pressure gage. Deletions

involved elimination of a keep full valve from the LN₂ line to the GN₂ chiller and a pilot operated check valve in the piping to each lift cylinder. Both of these deletions had no affect on performance of their associated systems.

CONCLUSION

This facility was well designed and constructed and met or exceeded all performance requirements with very minimal cost increases. In hindsight, the only real negative aspect to CBI's handling of the project was the unfortunate selection of the vacuum chamber supplier.

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